Abrasion of eroded dentin caused by toothpaste slurries of different abrasivity and toothbrushes of different filament diameter

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Abstract: OBJECTIVE: This study aimed to evaluate the impact of toothpaste slurry abrasivity and toothbrush filament diameter on abrasion of eroded dentin in vitro. METHODS: Eroded dentin samples (hydrochloric acid, pH 2.6, 15s) were brushed with 40 strokes in an automatic brushing machine using manual toothbrushes with different filament diameter (0.15, 0.20 or 0.25 mm). The toothbrushes were applied with a control slurry free of abrasive particles (RDA-value 10) or toothpastes slurries with different abrasivity (RDA-values 20, 50 or 100). Each erosive-abrasive cycle was followed by storage of the dentin samples in artificial saliva for 3h. After each 4 cycles, the samples were stored in artificial saliva for 15 h. After 60 cycles, dentin loss was measured by profilometry and statistically analysed by ANOVA and linear regression analysis. RESULTS: Dentin loss increased along with the RDA-value of the toothpaste slurries. The impact of the filament diameter on dentin loss was less evident compared to the RDA-value. However, toothbrushes with smaller filament stiffness caused higher dentin wear in all toothpaste slurry groups (RDA 20, 50 and 100) except for the paste-free control group (RDA 10). CONCLUSION: Abrasion of eroded dentin increased along with the RDA-value of the toothpaste slurry and with decreasing filament diameter of the toothbrush.

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Abrasion of eroded dentin caused by toothpaste slurries of different abrasivity and toothbrushes of different filament diameter

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Summary

Objective: This study aimed to evaluate the impact of toothpaste slurry abrasivity and toothbrush filament diameter on abrasion of eroded dentin in vitro.

Methods: Eroded dentin samples (hydrochloric acid, pH: 2.6, 15s) were brushed with 40 strokes in an automatic brushing machine using manual toothbrushes with different filament diameter (0.15 mm, 0.20 mm or 0.25 mm). The toothbrushes were applied with a control slurry free of abrasive particles (RDA-value: 10) or toothpastes slurries with different abrasivity (RDA-values: 20, 50 or 100). Each erosive-abrasive cycle was followed by storage of the dentin samples in artificial saliva for 3h. After each 4 cycles, the samples were stored in artificial saliva for 15h. After 60 cycles, dentin loss was measured by profilometry and statistically analysed by ANOVA and linear regression analysis.

Results: Dentin loss increased along with the RDA-value of the toothpaste slurries. The impact of the filament diameter on dentin loss was less evident compared to the RDA-value. However, toothbrushes with smaller filament stiffness caused higher dentin wear in all toothpaste slurry groups (RDA 20, 50 and 100) except for the paste-free control group (RDA 10).

Conclusion: Abrasion of eroded dentin increased along with the RDA-value of the toothpaste slurry and with decreasing filament diameter of the toothbrush.

Introduction

Hard tissue abrasion is regarded as potential adverse effect of mechanical plaque removal by toothbrushing.[1] It is generally assumed that even normal toothbrushing causes some degree of dentin but not of enamel abrasion over lifetime. The susceptibility to abrasive wear is increased when the dentin is frequently exposed to acids of endogenous or exogenous origin, which cause an erosive softening of the surface. Although it was shown that the organic matrix of dentin exposed during prolonged acidic challenges is resistant to brushing treatment to some extent,[2] several studies showed that brushing treatment increased the loss of eroded dentin.[3-5]

Toothbrushing abrasion is significantly related to the abrasivity of the toothpaste. This has been shown for sound dental hard tissues[6-8] and, in a few studies, also for eroded enamel and dentin.[9,10] Toothbrush abrasivity is analysed by a radiotracer method, which determines relative abrasivity of sound enamel and dentine (REA and RDA, respectively) compared to reference abrasives.

Besides, the toothbrush as a delivery vehicle of the toothpaste might influence abrasion, depending on characteristics of the toothbrush, such as type of brush, filament stiffness and filament end-rounding. In a previous study it was shown that electric and manual toothbrushes vary in their ability to wear eroded dentin.[11] Considering that harder toothbrushes lead to higher wear on sound dentin than medium brushes,[12] it is assumed that the hardness of the brushes also affect abrasion of eroded dentin. The stiffness of a toothbrush depends on various factors, such as modulus of elasticity, bristle and tuft diameter, number of tufts, the number of bristles per unit area packed into a tuft hole, and the trim length of bristles.[13] Moreover, the diameter of the filament play an important role as it determines the filament stiffness when the length and moduli of elasticity of the filaments are constant.

However, as yet the impact of toothpastes with different abrasivity and toothbrushes of different hardness on dentin wear has not been analysed systematically. Thus, the present study aimed to investigate the effects of toothpaste slurries with different RDA-values applied with toothbrushes with different filament diameter on abrasion of eroded dentin. The hypothesis tested was that dentin wear will increase along with the RDA-value of the toothpaste slurry and the filament diameter of the toothbrush.

Materials and methods

Preparation of dentin specimens

Ninety-six dentin samples (2.8 mm in diameter) were prepared from the root surfaces of freshly extracted, non-damaged bovine incisors, which were stored in 0.1% thymol solution until used. The samples were fixed with composite (Tetric flow, Ivoclar Vivadent, Schaan, Liechtenstein) in moulds of a ceramic disc (Degussit, Friatec/Degussa, Düsseldorf, Germany) and polished with water-cooled carborundum discs (1200, 2400 and 4000 grit, Water Proof Silicon carbide Paper, Stuers, Birmensdorf, Switzerland). Thereby, approximately 100-150 µm of the outermost dentin layer (together with the complete cementum layer) was removed as verified with a micrometer (Digimatic, Mitutoyo, Tokyo, Japan). The samples were equally distributed randomly among 12 groups of 8 specimens each and fixed in custom made resin appliances (Eracetal, Angst+Pfister, Zürich, Switzerland) allowing exact repositioning of the samples in both the wells of the brushing machine and the profilometer.

Baseline profiles were recorded, which were used as reference surfaces for the final determination of surface loss. As already shown previously, the ceramic ring is not affected by the brushing procedure.[5]

Preparation of toothpaste slurries

The baseline formulation of the slurries consisted of a mixture of saliva substitute (79.05 %) formulated by Göhring et al.,[15] 85% glycerine (10%), 1.62% sodium bicarbonate (10.3%), carboxymethylcellulose (CMC, 0.5%) and sodium fluoride (0.15%). This baseline formulation of the fluoride toothpaste slurries served as abrasive-free control and exhibited a RDA-value of 10. The composition of the three experimental slurries with low (RDA: 20), medium (RDA: 50) and high (RDA: 100) is shown in Table I.

RDA-values were determined by the radiotracer method using American Dental Association specifications (Oral Health Research Institute, Indiana University) as described previously [16]. RDA scores of the test slurries were related to a standard abrasive, calcium pyrophosphate, which is by definition given an RDA of 100.

Toothbrushing abrasion

Abrasion was performed with experimental toothbrushes (Paro M 43, Esro AG, Thalwil, Switzerland) exhibiting a flat trim and nylon filament diameters of 0.15, 0.20 or 0.25 mm. Additional information about the toothbrushes is given in Table II. The brushes were fixed in an automatic brushing machine [17,18] so that the long axes of the toothbrushes were at an angle of 12° to the direction of brushing avoiding the formation of tracks induced by the bristles on the dentin surface.

In each cycle, the samples were brushed with 40 strokes (2 stroke/s) using 2.5 ml of the respective slurry with a load of 2.5 N. In each cycle freshly mixed toothpaste slurries were applied.

Experimental setup

Each sample was cycled 60 times through erosion and abrasion. Each cycle consisted of 15 s erosion, brushing and storage in artificial saliva. Erosion was performed by unstirred storage of each sample in 1 ml hydrochloric acid (pH: 2.6, 0.0025 mol/L, Merck, Zug, Switzerland) for 15 s. After that, the samples were rinsed for 10 s with distilled water and brushed with the different toothpaste slurries (RDA 10, 20, 50 or 100) which were applied with the different experimental toothbrushes (filament diameter: 0.15, 0.2 or 0.25 mm). After each erosive-abrasive cycle, the dentin samples were stored in artificial saliva[19] for 3 h. Storage of artificial saliva was performed for 15 h after completion of four successive cycles. Final analysis of surface profilometry for assessing dentin loss was conducted after a total of 60 cycles.

Profilometry

Dentin loss was analysed profilometrically using a mechanical profilometer (Perthometer S2, Mahr, Göttingen, Germany). The profiles were obtained by moving the diamond stylus across the dentin surface and the references areas perpendicularly to the direction of the movement of the toothbrush. This assessment was done at baseline and after completion of 60 cycles. By means of the above mentioned moulds, an exact reposition in the profilometer was possible, which allows calculation of final dentin loss relative to the baseline profiles. Calculation was done using the software of the profilometer (Mahr Perthometer Concept 7.0, Mahr, Göttingen, Germany).

Statistical analysis

For calculation of dentin loss of each sample, the loss of the five recorded profiles was averaged. These data were further statistically analyzed by one-way ANOVA considering either the toothpaste slurry abrasivity (factor with 4 levels) or the filament diameter (factor with 3 levels) as independent variables. Moreover, linear regressions were determined in relation to the toothpaste slurry abrasivity and the filament stiffness. The level of significance was set at $p < 0.05$.

Results

Figures 1 and 2 illustrate the dentin loss (µm) in the different groups considering either the toothpaste slurry abrasivity (Fig 1) or the filament diameter (Fig 2) as independent variable. Linear regression analysis revealed that dentin loss increased along with the RDA-value of the toothpaste slurries (Fig 1). For each filament stiffness group, ANOVA revealed significant differences among the RDA-values of the toothpaste slurries.

From Fig 2 it can be obtained, that dentin loss increased also with decreasing filament diameter. Toothbrushes with smaller filament stiffness caused higher dentin wear in all toothpaste slurry groups (RDA 20, 50 and 100) except for the abrasive-free control group (RDA 10). However, the impact of the filament diameter on dentin loss was less evident compared to the RDA-value.

Discussion

As found for sound dental hard tissues[6-8] and eroded enamel,[10] abrasion of eroded dentin was mainly influenced by the abrasivity of the toothpaste and to a lesser extent by the toothbrush hardness. To mimic the clinical situation closely the toothpastes were used as slurries. Standardization of the experimental toothpastes with RDA 20, 50 and 100 was guaranteed by using calcium pyrophosphate as the only abrasive.

The observation that abrasion of eroded dentin increased along with the RDA-value confirms the results of Hooper et al.[9] who showed that a toothpaste with higher RDA (RDA 189) also caused higher wear on eroded dentin than a less abrasive toothpaste (RDA 85).

It might be assumed that toothpastes with lower abrasivity only abrade the outermost aspects of the demineralised dentin and the exposed collagen matrix. With higher abrasivity it seems to be more likely that also deeper parts of the erosively altered surface might be affected by brushing. The toothbrushes were applied with 2.5 N which refers to common values for brushing force.[20,21] The application of 40 brushing strokes to each sample is somewhat prolonged compared to the clinical situation of one single toothbrushing but corresponds to the amount of brushing strokes applied daily under clinical conditions.[9,22] In contrast to the results of Harte and Manly[12] who showed that the abrasion of sound dentin increased along with the hardness of the toothbrush, the results of the present study showed the opposite for eroded dentin. This observation might be explained by the greater flexion of the soft bristles leading to an increased duration and area of bristle contact to the brushed surface and thus, to an increased quantity of abrasives moving over the surface.[23] Moreover, it might be assumed that the capture efficacy of abrasives by a brush might be determined by the number of bristles per toothbrush as the number of bristles decreased with increasing filament diameter. Thus, the absence of any abrasives in the control slurry might explain why the toothbrushes did not perform differently when applied with the control slurry (RDA 10).

However, generally, it has to be taken into consideration that the correlation between the toothbrush filament diameter and abrasion was lower than the correlation between toothpaste abrasivity and abrasion. This demonstrates that abrasion of eroded dentin is mainly affected by the toothpaste abrasivity than by the toothbrush filament diameter.

The present design aimed to simulate a worse case scenario in patients suffering from dental erosion. For this, dentin samples were eroded briefly to imitate a bulimic acid attack.[24] The dentin samples were prepared from bovine teeth as it was recently shown that bovine dentin is an appropriate substitute for human dentin in erosion/abrasion tests.[25]

To focus on the abrasion potential of the slurry only, the experiments were carried out without storage in saliva in-between erosion and abrasion to avoid rehardening of the demineralised dentin. The findings of this study suggest that abrasion of eroded dentin is mainly affected by the abrasivity of the toothpaste, but also by the filament diameter of the toothbrush. Although the extrapolation from in vitro data to the clinical situation should be done with caution, the present data indicate that patients with erosive lesions affecting dentin should be advised to use toothpastes with low RDA-values to minimize dentin loss. In this context it is worth mentioning that the cleaning efficacy of the toothpaste is not only dependent on the RDA-value, but more related to the kind of abrasive used.[26] This implies that a low RDA is associated to less abrasion of eroded dentin surfaces, but not necessarily with distinctly limited cleaning properties of the respective toothpaste.

In conclusion, the working hypothesis tested that abrasion of eroded dentin will increase along with the RDA-value of the toothpaste slurry and the filament diameter of the toothbrush was partly rejected.

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Legends for tables and figures

Table I

Composition and mean particle diameter of the different toothpaste slurries. All slurries were supplemented with silicone antifoam to avoid slurry loss due to foaming during the brushing procedure. Particle size measurement was performed by Ivoclar Vivadent (Schaan, Liechtenstein) using a laser particle size analyser (CILAS 1064, liquid mode, CILAS, Madison, USA).

Table II:

Manufacturers´ information about the experimental toothbrushes

Fig. 1

Dentin loss (mean ± standard deviation) and regression lines for dentin loss with respect to RDA for three different filament diameters: ♦ = 0.15 mm ($r^2 = 0.85$, $p < 0.0001$), ■ = 0.2 mm ($r^2 = 0.42$, $p < 0.0001$) and ▲= 0.25 mm ($r^2 = 0.36$, $p = 0.0003$).

Fig. 2

Dentin loss (mean ± standard deviation) and regression lines for the dentin loss with respect to filament diameter for four different RDA-values: ♦ = RDA 10 ($r^2 = 0.05$, $p = 0.3$), ■ = RDA 20 ($r^2 = 0.38$, $p = 0.0014$), ▲= RDA 50 ($r^2 = 0.21$, $p = 0.024$) and x = RDA 100 ($r^2 = 0.23$, $p = 0.018$).

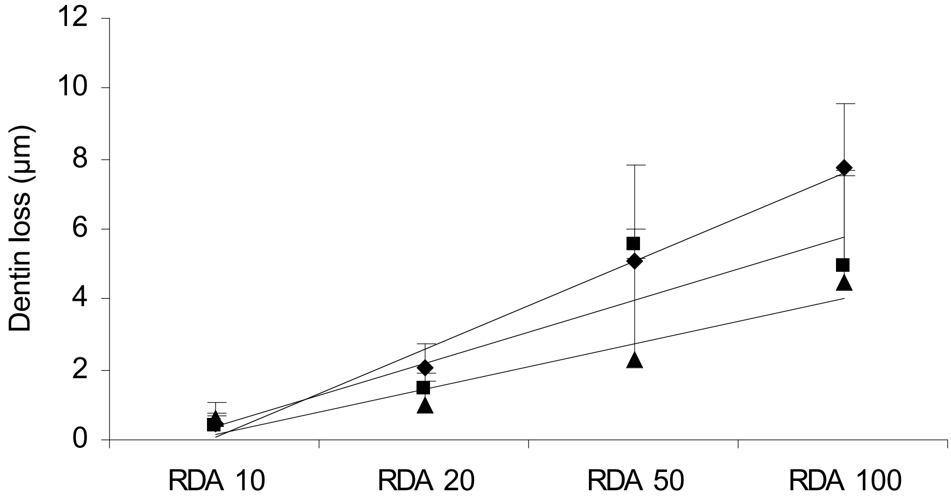

Fig. 1

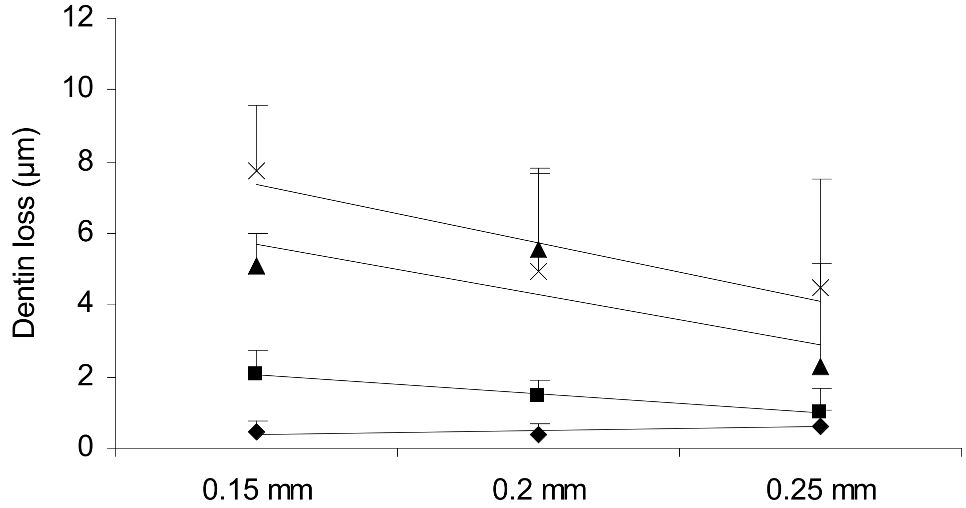

Fig. 2

Slurry composition	**RDA 20**	**RDA 50**	**RDA 100**
Baseline formulation	108 g	100 g	100 g
$Ca_2O_7P_2$ (Fluka Buchs, Switzerland, Lot:88H0466)	4 g	-	6.6 g
$Ca_2O_7P_2$ (Sident S 22, Degussa, Germany, No 1186)	8 g	-	-
$Ca_2O_7P_2$ (Reference abrasive ISO Toothpaste Specification 11609)	-	20g	-
$Ca_2O_7P_2$ (Budenheim KG, Germany, Lot: C-54-80)	-	-	13.4 g
Silicone antifoam (Fluka Buchs, Switzerland)	20 µg	20 µg	20 µg
Mean particle diameter	**7 µm**	**9.5 µm**	**9.1 µm**

Table I

Parameter	Paro M43 soft	Paro M43 medium	Paro M43 hard
Filament diameter (mm)	0.15	0.20	0.25
Bristle length (mm)	11	11	11
Tufts (No.)	43	43	43
Bristles/Tuft (No.)	60	36	20
Bristles/Toothbrush (No.)	2580	1548	860

Table II